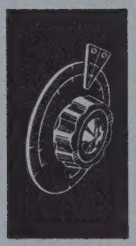
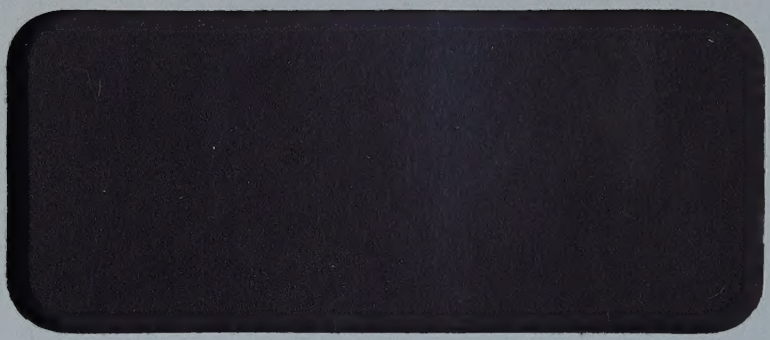
WAYNE KERR

ADAPTATION OF

V.H.F. ADMITTANCE BRIDGE B801

FOR MEASURING LOW IMPEDANCES





CORRECTION

Page 1, Admittance Limitations

Fifth line should read:

above 50Mc/s, and on susceptance is 0.2pF up to 100Mc/s.

Page 3, line 3

for 2000pF read 4700pF.

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V.H.F. ADMITTANCE BRIDGE B801

FOR MEASURING LOW IMPEDANCES

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ADAPTATION OF B801 FOR MEASURING LOW IMPEDANCES

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Tables 1 and 2

Fig.1(a) Bridge Terminal Connexions
Fig.1(b) Simplified Circuit
Fig.2 Circuit Showing Stray Impedances
Fig.3(a) and (b) Connexion of the Unknown
Fig.4 Suggested Component Lay-out

ADAPTATION OF B801 FOR MEASURING LOW IMPEDANCES

Introduction

The method of measurement is similar to that employed with the Wayne Kerr Low Impedance Adaptor Q221 but is modified to suit the higher frequencies. Slight differences exist (compared with, for example, Bridge B221) in the manner of connecting the T-network to the Bridge and in the initial balancing procedure. These processes are described fully in subsequent paragraphs.

Admittance Limitations

The specification of V.H.F. Admittance Bridge B801 states that conductance in the range of 0 to 100 millimhos and susceptance equivalent of -230pF to +230pF over the frequency range 1 to 100 Mc/s can be measured. The discrimination is 0·02 millimho for frequencies up to 50 Mc/s, 0·1 millimho above 50 Mc/s, and on susceptance is ~~2 per cent~~ 0·2pF up to 100 Mc/s. This range has proved adequate for most measurements but, with the rapid development of semiconductors, instruments will be required that are capable of measuring the parameters of these devices in a straightforward manner. Existing instruments are often not suited to such measurements because semiconductors have the form of a complex impedance consisting of resistance in series with reactance, the latter being predominantly negative (i.e. capacitive). The actual values and proportions of resistance and reactance depend on the composition of the semiconductor. With some germanium or silicon crystals the resistance is predominant and the reactance value small, whilst with some titanate crystals both resistance and reactance are very small, the latter especially so when a high frequency is used for measurement.

In the case of the first group above, the Bridge B801 can be used in a straightforward manner to measure the equivalent parallel components of

conductance and capacitance. When the resistance falls below 10 ohms and the equivalent parallel capacitance exceeds 230pF, the Bridge range must be extended by means of the T-network to be described. Care must be exercised in interpreting results when the impedances are of the order of 5 to 10 ohms, but very few limitations exist when measuring impedances of less than 5 ohms. Small resistances and reactances can, in general, be measured to an accuracy of 5 per cent.

Frequency Limitations

The bridge construction is very compact and simple but certain limitations exist on the highest frequency at which the extension method can be used. This frequency will, in general, be of the order of 50 Mc/s, although useful information can still be obtained at higher frequencies if the measurement is made with care.

An equivalent circuit of the Bridge is shown in Fig. 2. By referring to this it can be seen that errors may arise at higher frequencies due to:

1 Self-impedance of the Neutral and block terminals.

2 Mutual impedances as shown.

3 Reactance of resistors used in the extension network.

4 Careless connexions and/or lay-out of the series resistors in the extension network or the component to be measured.

As an example, suppose that the component is mainly capacitive, with a value of approximately 3000pF and is to be measured at 20Mc/s. The reactance in this instance is $-j2{\cdot}7\Omega$. In practice two leads (or strips) will be fitted to the component to be measured as a means of connexion. If the inductance of these leads, or a loop formed by careless wiring, results in an inductance of only 8 millimicrohenerys, this is equivalent to a reactance of $+j1\ \Omega$.

The Bridge, in such circumstances, can measure only the resultant reactance of $-j1{\cdot}7\Omega$, corresponding to a capacitance of ~~2000pF.~~ 4700pF.

Subsequent sections describe in detail the procedures which will reduce errors arising from causes 1 to 4 to very small proportions.

Principle of Extension Method

The disposition of the Bridge terminals, together with their connexions to the internal circuits, is shown in Fig. 1(a). A simplified circuit diagram of the Bridge, Fig. 1(b), illustrates also the series resistors R of the extension network and the unknown impedance, Z_u, connected between the junction of these two components and neutral.

When the Bridge is balanced, the voltage across the current transformer is, for all practical purposes, zero. The right-hand resistor R is therefore effectively in parallel with the unknown small impedance Z_u. If the value of this resistor is very high compared Z_u, the shunting effect is negligible and can be ignored. The current through Z_u is then equal to $E/(R + Z_u)$, R being the left-hand resistor. If this R, also, is made very high compared with Z_u, the effect on the current 'i' is negligible and can be ignored. With these approximations:

current through Z_u, $i = E/R$,
voltage across Z_u, $e = Z_u \times E/R$ and
current fed to T2, $I = e/R = Z_u \times E/R^2$.

Thus $Z_u = R^2 \times I/E$ .....(1)

Since the ratio I/E represents the admittance given by the Bridge dial readings, the value of the unknown impedance can be written:

$Z_u = r_u \pm jx_u = R^2 [G \pm jB]$ .....(2)

where G and B ($=\omega C$) are in mhos, all other values in ohms, and $x_u = \omega L_u$ or $-1/(\omega C_u)$.

It follows from equation (2) that:

$$r_u = R^2G \quad \ldots\ldots\ldots\

Bridge Stray Impedances

Within the Bridge itself there is a number of self- and mutual inductances and small series resistances, between block terminals, neutral connexions and plates, transformer leakage elements, etc. Where the self-inductances and resistances are in series with either the Standards or the resistors R, their influence can be ignored, since they give rise to impedances much smaller than the value of the Standards or R.

This is not necessarily true with mutual coupling between various parts of the Bridge structure unless during the whole procedure of measurement the distribution of currents and their actual values remain nearly constant. In Fig. 2 some of the self- and mutual impedances in the Bridge are shown. It can be seen that if, during a measurement, the value of currents i or I changes the mutually coupled voltages governed by M_1 to M_3 may modify the results considerably. Similarly, if the position or resistors R was changed, variations in the self- and mutual inductance or in the stray field due to wiring loops could give rise to errors.

There are two methods of obtaining the value of a small impedance Z_u.

Method 1

1 With the unknown impedance out of the circuit, the two resistors R are joined together at one end, preferably with a short strip of metal, and this is connected to the Neutral terminal. The other ends of the components are connected one to each of the two measurement terminals.

2 The Bridge is balanced for null by means of the Trim G and Trim C controls.

3 The junction of the two resistors is then disconnected from the Neutral terminal and the Unknown, Z_u, connected between this junction and the Neutral terminal.

4 The Bridge is balanced for null using the main (front-panel) G and C controls. The value of Z_u is then derived from equations (3) to (5) given earlier or, if necessary, from equation (6).

This method is convenient but the accuracy deteriorates at the higher frequencies because the physical introduction of the Unknown may modify the stray fields in the vicinity of the terminals.

Method 2

1 The Unknown is connected in series with one of the resistors R and the combination connected between the voltage terminal A and Neutral (see Fig. 2). The second resistor is connected between the current terminal B and Neutral. The leads must be as short as possible but the second resistor is so positioned that the short lead to Neutral can subsequently be moved to position (2) without re-positioning the component.

2 The Bridge is balanced for null by means of the Trim G and Trim C controls.

3 The lead from the second resistor is then moved from position (1) (Neutral) to position (2) (the junction of the first R and the Unknown).

4 The Bridge is balanced for null using the main (front-panel) G and C controls. The value of Z_u is then derived, as with Method 1, from equations (3) to (5), or 6.

The advantage of this method over Method 1 is that the lay-out of the components during the actual measurement is the same as for the initial balance. Provided that Z_u is small compared with R, the change in p.d. across Z_u when the resistor connexion is moved from position (1) to (2) will be very small and the current i will remain practically unaltered.

The value of Z_u is obtained without the potential drops occurring across the self-inductance L_N and resistance r_N affecting the result. In both methods it is assumed that the position of resistors R is not altered between the initial trim and the final measurement.

Choice of Value of R

Suitable values of R depend on the value of the unknown impedance and the frequency of measurement. It is not possible to specify values for all conditions but the summary of data in Table 1 is supplied for general guidance.

At the low end of the frequency range much larger values of R can be used than is possible at higher frequencies, but the Bridge standards should not be operated at very low settings or the accuracy of reading falls off. As a general rule, the Bridge conductance reading should not fall below 0·1 millimho, and capacitance should not be much less than ±5pF. This limitation may, at higher frequencies, indicate the required value of R to be less than 33 ohms, in which case inaccuracies will be introduced due to the rather high series inductance associated with such components. At frequencies above 3Mc/s, the value of R should never exceed 500 ohms. The type of resistor used is important and suitable components are described in the next section.

Choice of Type of R

The resistors used in the extension network must be stable and non-reactive. High-stability carbon resistors, of non-spiral construction, are the most suitable components. The size is important and the resistors should be small - preferably of diameter less than 1/4 in. and length less than 3/4 in. The connecting leads should be cut short and replaced, preferably, by short sturdy spade terminals that can be inserted under the Bridge terminals. This will reduce the series inductance to a minimum. The resistors should be positioned along the top of the terminals, about 1/16in. above them.

Connexions to the Unknown

Detailed attention must be paid to the method of connecting the Unknown or serious errors may arise, particularly at the higher frequencies. In Fig.3(a) is illustrated a large-value capacitor with its leads formed into loops for connexion to the terminals. The inductance so formed will cause an inaccurate result to be obtained.

The correct method of connecting such a component is shown in Fig. 3(b). The left-hand lead has been cut short and is taken directly to the terminal or R junction. The other lead also is shorter than in 3(a) and is connected to a copper sheet which is taken along the body of the capacitor and formed to fit under the Neutral terminal. This method of connexion reduces the inductance present in 3(a) by a factor of at least 10.

Note: The lengths of lead shown in Fig.3(b) are extended for clarity in the illustration. In practice, these must be kept to an absolute minimum.

Component Lay-out

The suggested lay-out of the resistors R and the unknown impedance, assumed here to be a capacitor, is shown in Fig. 4 in relation to the measurement terminals. These positions are not changed between the initial and final balance operations. To obtain reliable contact at junctions (1) or (2) it may be advantageous to use small screws or have soldered connexions. Before the final measurement is made at the desired frequency (applying the procedure in the next section), it is worth while checking that, at the highest frequency, the results are not affected by small changes in the position of components.

Measurement Procedure

This procedure is based on Method 2, described earlier. If a number of comparison measurements are required at the lower frequencies, it may be more convenient to modify the operation to comply with Method 1. The second method provides greater accuracy at the higher frequencies.

1 Prepare the components in the manner described in preceding sections.

2 Remove the triangular plate shorting the current terminal to Earth.

3 Connect the components to the terminals (refer to the suggested lay-out of Fig.4) with the right-hand lead of the resistor from the current terminal connected to point (1) (the Neutral terminal or copper sheet from this terminal).

4 Balance the Bridge for null by means of the Trim G and Trim C controls.

5 Remove the resistor connexion from the Neutral terminal and instead connect the component to point (2) (junction of the other resistor and the Unknown).

6 Balance the Bridge for null with the main (front-panel) G and C controls. Record the settings and interpret the result by using equations (3) to (5) or equation (6).

Conclusions.

The method described will in general apply up to a frequency of about 50 Mc/s. Above this limit, when the influence of series and mutual inductances increases rapidly, the values of R required will fall below 33 ohms. Such resistors display heavy self-inductance and cannot be relied upon.

Results obtained using the extension network are not perfect, but in general the value of a small impedance (e.g. a coil) used at high frequencies is not required to a high degree of accuracy as final adjustment is carried out in the actual circuit in which it is used.

TABLE 1

Frequency Range 1 - 40 Mc/s

COMPONENT MEASURED	FORMULA	VALUES OF R	MEASUREMENT RANGE	CONDITION REQUIRED
r_u =	$R^2.G$	200-33Ω	10-0·05Ω	$r_u \leqslant R/25$
L_u =	$R^2.C$	330-33Ω	20μH at L.F. falling to a few millimicro henrys at H.F.	$\lvert\omega L_u\rvert \leqslant R/5$
C_u =	$1/(\omega^2 R^2 C)$	1000-33Ω (see Table 2)	250-10000pF	$\lvert 1/(\omega C_u)\rvert \leqslant R/5$

TABLE 2

Examples

This table is a guide to suitable values of R for measuring capacitances of 500, 1000 and 3000pF at selected frequencies between 1 and 40Mc/s. Corresponding values of R for small inductances and resistances can be derived from Table 1.

FREQUENCY	COMPONENT MEASURED	VALUE OF R	APPROXIMATE BRIDGE READING
1 Mc/s	500pF	1000Ω	55pF
1 Mc/s	1000pF	600Ω	60pF
1 Mc/s	3000pF	300Ω	80pF

Continued.....

/Examples continued ....

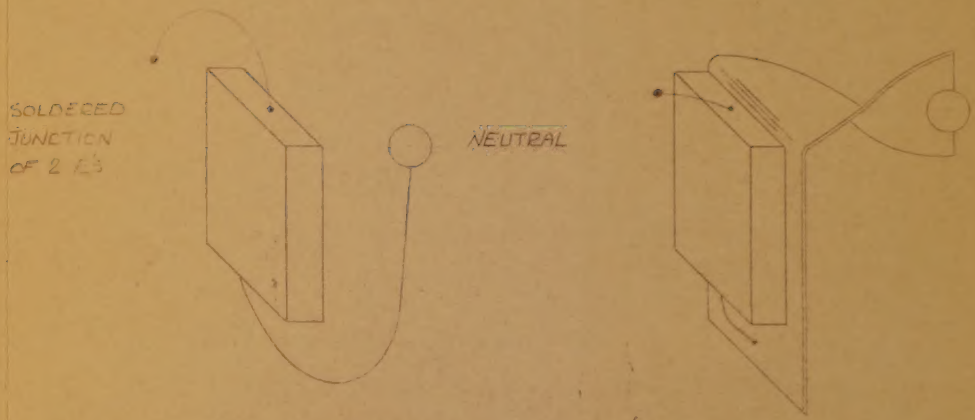
2 Mc/s	500pF	800Ω	55pF
2 Mc/s	1000pF	400Ω	110pF
2 Mc/s	3000pF	200Ω	50pF
5 Mc/s	500pF	300Ω	22pF
5 Mc/s	1000pF	200Ω	25pF
5 Mc/s	3000pF	100Ω	33pF
10 Mc/s	500pF	200Ω	25pF
10 Mc/s	1000pF	100Ω	25pF
10 Mc/s	3000pF	50Ω	32pF
20 Mc/s	500pF	70Ω	24pF
20 Mc/s	1000pF	50Ω	24pF
20 Mc/s	3000pF	50Ω	8pF
30 Mc/s	500pF	50Ω	22pF
30 Mc/s	1000pF	50Ω	11pF
30 Mc/s	3000pF	33Ω	8pF
40 Mc/s	500pF	50Ω	12pF
40 Mc/s	1000pF	50Ω	6pF
40 Mc/s	3000pF	33Ω	5pF

NOTE: 1 L.F. and H.F. in Table 1 refer to frequencies near 1 and 40 Mc/s respectively.

2 When resistance and reactance are present, the value of R should be selected to suit the major component (i.e. that with the greater ohmic value).

FIG 1 (a) BRIDGE TERMINAL

STANDARDS



CONNEXION OF THE UNKNOWN

FIG 3 (a) INCORRECT METHOD INTRODUCING INDUCTIVE LOOPS

FIG 3 (b) CORRECT METHOD USING SHORT LEADS AND COPPER STRIP

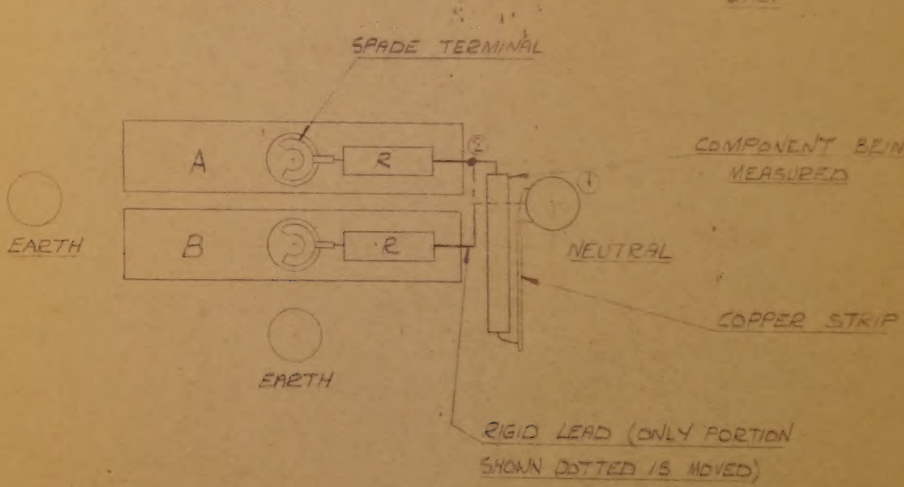


FIG 4 SUGGESTED COMPONENT LAYOUT

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